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THE SHADOW INFRASTRUCTURE OF GLOBAL TRADE: HOW SANCTIONS PRESSURE GENERATES PARALLEL LOGISTICS AND FINANCING CHANNELS

The article conceptualizes the shadow infrastructure of global trade as a structural consequence of infrastructural decoupling and sanctions pressure. It argues that restricted access to the legitimate infrastructure of international trade generates a concealed infrastructure reproducing the functions of transport, registration, insurance, and settlement beyond international oversight. A two-circuit model is proposed, comprising material and logistics, and financial and digital circuits. Their interaction enables the coordinated concealment of goods movement and related financial flows, making the architecture of trade transactions rather than their individual characteristics the primary object of concealment. The study concludes that effective de-shadowing policies should target the infrastructural mechanisms ensuring the resilience and self-reproduction of shadow trade.

Keywords: de-shadowing, shadow economy, shadow fleet, sanctions pressure, critical supply chain infrastructure, logistics flows, financial and digital infrastructure, stablecoins, payment systems, cryptocurrency payments.

JEL classification: F13, F52, F55, G23, K42.

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ТІНЬОВА ІНФРАСТРУКТУРА ГЛОБАЛЬНОЇ ТОРГІВЛІ: ЯК САНКЦІЙНИЙ ТИСК ПОРОДЖУЄ ПАРАЛЕЛЬНІ КОНТУРИ ЛОГІСТИКИ ТА ФІНАНСУВАННЯ

У статті досліджено тіньову інфраструктуру глобальної торгівлі як структурний наслідок інфраструктурного декаплінгу та посилення санкційного тиску. Обґрунтовано, що обмеження доступу окремих держав до легальної інфраструктури міжнародного товароруху зумовлює формування не лише відкритих паралельних контурів, а й прихованого контуру, який відтворює функції критичної інфраструктури поза межами дії міжнародних механізмів контролю. Доведено, що тіньові практики, які в наявних дослідженнях переважно розглядаються як окремі явища, доцільно трактувати як цілісну інфраструктуру з власною архітектурою та внутрішньою логікою самовідтворення.

Запропоновано двоконтурну модель тіньової інфраструктури, що поєднує матеріально-логістичний і фінансово-цифровий контури. Матеріально-логістичний контур охоплює тіньовий флот, реєстри прапорів зі слабким наглядом та альтернативні механізми страхування, тоді як фінансово-цифровий контур включає розрахунки у стейблкоїнах і альтернативні платіжні канали. Встановлено, що взаємодія цих контурів забезпечує цілісне функціонування тіньової інфраструктури: матеріально-логістичний контур забезпечує переміщення товарів, фінансово-цифровий – переміщення пов'язаної з ними вартості, тоді як обидва одночасно приховують різні аспекти однієї й тієї самої торговельної операції. Унаслідок цього об'єктом приховування стають не окремі характеристики операції, а сама можливість зіставлення задекларованих відомостей із фактичним рухом товарів і фінансових потоків. Показано, що архітектурна взаємодія матеріально-логістичного та фінансово-цифрового контурів формує новий рівень стійкості тіньової торгівлі, за якого взаємозамінність окремих елементів забезпечує безперервність функціонування всієї системи навіть за умов посилення санкційного контролю. Обґрунтовано, що точковий вплив на окремі елементи тіньової інфраструктури змінює лише її конфігурацію, не порушуючи принципів функціонування всієї архітектури. Доведено, що ефективність політики детінізації визначається не масштабами санкційного тиску як такими, а здатністю впливати на інфраструктурні механізми координації логістичних, фінансових та інформаційних потоків. На цій підставі визначено, що найбільш результативним напрямом політики детінізації є вплив на інфраструктурні механізми, які забезпечують стійкість і здатність тіньової інфраструктури до самовідтворення.

Ключові слова: детінізація, тіньова економіка, тіньовий флот, санкційний тиск, критична інфраструктура ланцюгів постачання, логістичні канали, фінансово-цифрова інфраструктура, стейблкоїни, платіжні системи, криптовалюти розрахунки.

Introduction. The implementation of global infrastructure projects is undergoing a profound transformation amid geo-economic fragmentation, while the architecture of connectivity itself is increasingly becoming an instrument of strategic control. The logical continuation of this line of analysis is the question of what happens to a state whose access to the legal infrastructure of international goods movement is restricted under a sanctions regime. The answer that has taken shape in the specialized literature typically reduces to an enumeration of individual circumvention schemes: the purchase of old tankers, the change of flag, the disabling of identification systems, settlements bypassing international clearing. The totality of these practices is no longer a set of disparate techniques but has acquired the features of an infrastructure, that is, a stable, self-reproducing system providing a defined range of services, namely transport, insurance, settlement, and registration, beyond the reach of oversight mechanisms [1; 2].

According to industry analysts, by late 2025 the shadow fleet comprised approximately 978 tankers with a combined deadweight capacity exceeding 127 million tonnes, corresponding to roughly 18.5 % of the global tanker fleet [3]. In parallel, the illicit circulation of cryptoassets reached a record 154 billion dollars in 2025, with more than 104 billion dollars attributable to sanctioned entities,

representing a 694% increase over the preceding year [4-7]. The juxtaposition of these two datasets demonstrates that they are two links in a single mechanism, in which the physical movement of goods and the movement of the corresponding value are coordinated to withdraw from oversight. This is what necessitates conceptualizing shadow infrastructure as a coherent phenomenon rather than a collection of discrete episodes of sanctions circumvention.

Literature review. Research on the shadow infrastructure of global trade is taking shape at the intersection of three thematic strands. The first strand comprises works on the transformation of global infrastructure amid fragmentation. H. Farrell and A. Newman have demonstrated that global connectivity is increasingly used as an instrument of strategic pressure, and that economic interdependence is transformed into a lever of coercion that shapes the vulnerabilities of global networks [1]. A distinct line is represented by the work of H. W.-c. Yeung, who interprets the reconfiguration of trade flows not as a retreat from globalization but as its fragmentation into competing contours of connectivity [2]. These studies outline the potential consequences of the shift towards new models of infrastructure investment that alter the configuration of global logistics routes.

The second strand is represented by empirical studies

of sanctions circumvention and the functioning of the shadow fleet. Experts at S&P Global document the sustained growth in the number of shadow fleet vessels and in their combined deadweight capacity [3]. E. Braw, in a report for the Atlantic Council, traces the migration of vessels between flag registries with weak oversight, the practice of ship-to-ship transfers on the open sea, and the disabling of automatic identification systems [4]. Experts at RUSI argue that flag registries constitute a structural vulnerability in the sanction regime, since a change of flag occurs faster than supervisory authorities can respond [5]. J. Macias and B. Jensen, in a CSIS study, assess the fleet's age structure and the level of its insurance coverage [6]. In parallel, a separate strand of monitoring the illicit circulation of cryptoassets has emerged: analysts at Chainalysis have traced the displacement of sanctions circumvention towards stablecoin settlements and the formation of specialized payment channels [7], while experts at TRM Labs record the accelerating growth in the volume of such settlements and assess the share of sanctioned flows within the overall scale of crypto crime [8].

The third strand concerns critical infrastructure as an object of geo-economic competition. The broader tradition of conceptualizing the illicit economy as a coherent transnational phenomenon, established by the works of M. Naím and L. Shelley, within which the interchangeability of legal, illegal, and intermediate goods along shared supply chains has been demonstrated [9; 10], has until now scarcely been combined with an infrastructural perspective. J. Collins has argued that cryptoassets are being transformed from an auxiliary instrument of payment into an autonomous financial infrastructure for cross-border shadow exchange [11], while the investigation by S. Woodman and colleagues has demonstrated that weakened identification procedures enable the servicing of flows associated with sanctioned entities [12]. Supervisory bodies, particularly the FATF, identify stablecoins and wallets outside regulated services as a key challenge to controlling cross-border settlements [13]. Estimates of the scale and structure of the global illicit economy are presented in the GI-TOC report [14], while data on the structure of illegal markets are summarised in the UNODC report [15].

The common limitation of the existing research is the object-by-object character of the analysis. The shadow fleet is studied separately from crypto channels; flag registries are studied separately from insurance practices; and these phenomena are studied separately from the concept of infrastructural decoupling. What is lacking is a framework that would treat the totality of shadow practices as a single infrastructure with its own architecture and logic of self-reproduction. Filling this gap constitutes the task of this article.

Despite the significant body of research on sanctions circumvention, the shadow fleet, flag registries with weak regulatory oversight, alternative insurance arrangements, and the illicit circulation of cryptoassets, these phenomena continue to be examined as separate objects of analysis rather than as interconnected components of a single infrastructural system. Existing studies have substantially advanced understanding of individual mechanisms of

sanctions evasion, the operational logic of shadow maritime transport, and the growing role of cryptoassets in illicit financial flows. However, they have not yet explained why these diverse practices demonstrate comparable capacities for resilience, adaptation, and rapid reconstruction under increasing regulatory and sanctions pressure. As a result, the mechanisms through which physical logistics, financial settlements, registration services, and insurance arrangements become integrated into a coherent architecture of shadow trade remain conceptually underdeveloped. This fragmentation of the literature obscures the systemic nature of the phenomenon, since the effectiveness of shadow trade stems not from the operation of any individual mechanism but from the interaction of mutually reinforcing infrastructural elements. The present study addresses this conceptual gap by interpreting shadow trade infrastructure as a unified, self-reproducing system composed of complementary material, logistical, financial, and digital contours. Such an approach makes it possible to explain not only the persistence of sanctions circumvention despite growing enforcement efforts, but also the adaptive capacity of shadow trade networks to reconstruct disrupted links, substitute individual service providers, and preserve the continuity of international trade operations under conditions of infrastructural decoupling. This perspective shifts the analytical focus from isolated instruments of sanctions evasion to the architecture of the infrastructural environment that enables their coordinated functioning.

The purpose of the article is to conceptualize the shadow infrastructure of global trade as a coherent phenomenon; to identify its two-contour structure, combining a material and logistical contour with a financial and digital contour; to reveal the mechanism of their fusion; and to determine the consequences of this phenomenon for de-shadowing policy.

The methodological basis of the study. The study employs a combination of general scientific and specialized research methods. The systems approach was used to conceptualize the shadow infrastructure of global trade as an integrated architecture consisting of two complementary circuits: the material and logistical circuit and the financial and digital circuit. Structural-functional analysis was used to identify the functions of the shadow fleet, weakly supervised flag registries, alternative insurance arrangements, stablecoin-based settlements, and alternative payment channels, as well as to reveal the mechanisms of interaction among these elements. The comparative method was used to distinguish the shadow infrastructure from the legal infrastructure of international trade and from open parallel connectivity circuits. Scientific abstraction was employed to develop the proposed two-circuit model of shadow infrastructure and to formulate its conceptual foundations. The method of generalization was used to substantiate the implications of the proposed concept for international de-shadowing policy. The tabular method was employed to systematize and present the structural characteristics of the proposed model.

Main results of the research. The shadow infrastructure of global trade may be defined as a functional duplicate of the critical infrastructure of goods movement,

reproducing its basic services, namely transport, insurance, settlement, and registration, beyond the reach of supervisory and regulatory mechanisms. The key feature here is precisely its infrastructural rather than episodic character: what is at issue is not an individual act of circumvention but a stable system capable of restoring lost links and servicing a recurrent flow of trade operations. The proposed concept requires demarcation from three adjacent ones. First, shadow infrastructure differs from the legal parallel contour, which is represented by recognized infrastructure initiatives and alternative payment systems that operate openly within their own jurisdictions. Second, it differs from an individual circumvention scheme in that it possesses the property of self-reproduction: the removal of a single element does not terminate its functioning. Third, it is narrower than the shadow economy, since it concerns specifically the infrastructural provision of international goods movement rather than the entire body of informal economic relations.

The nature of shadow infrastructure follows directly from the logic of infrastructural decoupling [16]. If legal decoupling splits global connectivity into competing yet open contours, sanctions pressure generates its concealed variant, in which the functions of the restricted legal infrastructure are assumed by a network of opaque intermediaries. Previous research has demonstrated that infrastructure at the point of structural decoupling becomes the object of geo-economic competition, with fragmentation and re-nationalization redefining the terms of that competition [17], while the logic of development restraint and the regulatory and institutional rivalry of the leading centers of the world economy determine the conditions under which such restriction occurs [18]. The methodological foundations for analyzing economic dependence under conditions of bipolar zoning of the world economy establish the

framework for assessing these asymmetries [20].

The material and logistical contour of shadow infrastructure is constituted by the physical movement of goods. The basis of this contour is the shadow fleet, comprising predominantly old tankers acquired through chains of opaque intermediaries. The fleet is estimated to range from 155 to 591 vessels, of which approximately 72% are more than 15 years old and 60% lack insurance coverage [6]. The functioning of this contour rests upon several enabling links. The first is the system of flag registries with weak oversight, through which vessels repeatedly change their registration jurisdiction. Following intensified pressure on traditional registries, the role of flags of states with limited supervisory capacity has increased, while a significant proportion of vessels remain under flags entered on the grey lists of international memoranda [4]. The second link is alternative insurance beyond the recognized associations of insurers, which permits voyages to continue without coverage acceptable to the legal market. The third link is the practice of ship-to-ship transfers at sea and the disabling of automatic identification systems, which makes it impossible to compare the declared route with the actual one.

The self-reproducing character of this contour is confirmed by its response to sanctions pressure. Despite the consistent expansion of sanctions lists, the fleet has not contracted but has grown, according to certain estimates, from 889 tankers in late 2024 to 978 in September 2025 [3]. The removal of an individual vessel from circulation does not dismantle the scheme, since it is replaced by another within the same network of intermediation. It is also indicative that among the new vessels that began servicing sanctioned deliveries during 2025, a substantial proportion remained outside any sanctions jurisdiction [5], which testifies to the fleet's reproduction outpacing the rate of sanctions response.

Table 1

Elements of the material and logistical contour of shadow infrastructure

Element	Function	What is concealed	Reach for the regulator
<i>Shadow fleet of old tankers</i>	Physical transport of cargo	Ownership of the vessel and its link to sanctioned cargo	Partial, through the arrest of individual vessels
<i>Flag registries with weak oversight</i>	Legal legitimization of the voyage	The actual ultimate owner of the vessel	High, through pressure on flag states
<i>Alternative insurance</i>	Coverage of the voyage beyond the legal market	The absence of acceptable insurance coverage	High, through supervision of the insurance market
<i>Ship-to-ship transfer and disabling of identification</i>	Masking of the route and origin of cargo	The actual route and destination	Low, owing to the technical difficulty of control

Source: compiled by the authors.

The financial and digital contours of shadow infrastructure are constituted by the movement of value that corresponds to the physical movement of goods. The restriction of sanctioned entities' access to international clearing and correspondent networks has led to the formation of alternative settlement rails, in which stablecoins, that is, cryptoassets pegged to national currencies, have assumed a central role. In 2025, stablecoins accounted for approximately 84% of the total illicit circulation of cryptoassets, reflecting the shift by sanctioned entities toward liquid instruments suited to rapid cross-border settlement [7]. Supervisory bodies note that it is precisely stablecoins and wallets

outside regulated services that are becoming the key challenge for controlling cross-border settlements [13]. The most striking example of the purposeful creation of a settlement channel has been the rouble-pegged stablecoin, which, in less than a year, serviced operations exceeding 93 billion dollars and effectively served as a specialized settlement system for sanctioned entities in cross-border trade [7].

The architectural property of this contour is the elimination of the verifying intermediary. In the legal financial infrastructure, the correspondent bank and the clearing center verify the participants in an operation. In the

financial and digital contour of shadow infrastructure, this function is either absent or reduced to a minimum through services with weakened customer identification procedures. Consequently, it becomes impossible to compare the parties to an operation, and the settlement itself becomes invisible to supervisory authorities. Investigations into the movement of funds through major cryptoasset operators demonstrate that it is precisely weakened identification procedures that enable the servicing of flows associated with sanctioned and criminal entities [12]. It is of principal importance that this contour reproduces the same logic of self-reproduction as the material one. The closure of an individual platform or the addition of an individual token to a sanctions list does not terminate settlements, as flows migrate to new services and instruments. The growth rate in illicit circulation, which increased by 694% over the preceding year [7], demonstrates that the existing supervisory instruments do not disrupt the contour's architecture.

The central thesis of this study is that the material and logistical contours and the financial and digital contours are not parallel and independent but constitute complementary links within a single mechanism. The material contour moves the goods, the financial contour moves the corresponding value, and both mask the same trade operation

from different sides. A tanker with its identification system disabled conceals the cargo's physical route, while settlement in a stablecoin conceals the financial trace of the same delivery. It is precisely the fusion of these two contours that ensures the completeness of concealment, since the detection of only the physical or only the financial trace does not restore the full picture of the operation. This fusion confirms a more general regularity in the transformation of shadowization, consisting of a displacement of the object of concealment. Whereas traditional forms of trade shadowization were directed at distorting the value parameters of an operation, that is, the customs value or country of origin, shadow infrastructure is directed at concealing the architecture of the operation itself, namely the actual route, the ultimate recipient, the ownership structure, and the system of financial support. The object of masking becomes not the declared magnitude but the very possibility of comparing the declared with the actual. This regularity is consistent with estimates of the scale and structure of the global illicit economy [14] and with the conclusion that cryptoassets are being transformed from an auxiliary instrument of payment into an autonomous financial infrastructure of cross-border shadow exchange [11] (Table 2).

Table 2

The two-contour model of the shadow infrastructure of global trade

Parameter	Material and logistical contour	Financial and digital contour
Basic service	Transport of goods	Settlement for goods
Key elements	Shadow fleet, flag registries, and alternative insurance	Stablecoins, alternative payment channels, and services with weakened identification
Object of concealment	The actual route and ownership of the vessel	The actual parties and the financial trace of the operation
Eliminated intermediary	The recognized insurer and the oversight of the flag state	The correspondent bank and the clearing centre
Reach for the regulator	Partial, through the physical attachment to ports and insurance	Low, owing to the decentralized character of settlements

Source: compiled by the authors.

The juxtaposition of the two contours makes it possible to identify a substantive difference between shadow infrastructure and legal decoupling in terms of the character of resilience. Legal decoupling generates resilience through diversification, in which duplicating routes and suppliers reduces the system's vulnerability to individual disruptions. Shadow infrastructure generates a different variety, which may be designated as the resilience of evasion, that is, the robustness of the concealment scheme itself to supervisory and sanctions pressure. In the first case, duplication serves the reliability of supply; in the second, it serves the durability of evasion from control. The formation of new centers of economic growth under the conditions of the new normal of the world economy creates the environment in which this second variety of resilience takes shape [19; 21].

Conclusions. The findings of this study provide grounds for interpreting the shadow infrastructure of global trade as a structural consequence of infrastructural decoupling, reproducing a concealed layer of global connectivity that operates alongside the legal architecture of international trade. Rather than generating only openly competing

logistical and financial systems, sanctions pressure also stimulates the emergence of hidden infrastructural arrangements that replicate the essential services of transport, registration, insurance, and settlement beyond the reach of conventional supervisory mechanisms. This demonstrates that contemporary shadow trade should be understood not as a collection of isolated sanctions-evasion practices but as an integrated infrastructure with its own architecture, functional specialization, adaptive capacity, and mechanisms of self-reproduction.

The proposed two-contour model explains the internal organization of this infrastructure and reveals the functional complementarity between its material and logistical contour and its financial and digital contour. The former ensures the physical movement of goods through the shadow fleet, weakly supervised flag registries, and alternative insurance mechanisms, whereas the latter enables the movement of the corresponding value through stablecoin settlements and alternative payment channels. Their interaction creates a unified concealment mechanism in which physical logistics and financial settlements simultaneously obscure different dimensions of the same

commercial transaction. Consequently, the primary object of concealment is no longer the declared value or origin of goods but the possibility of reconstructing the complete architecture of a trade operation through the comparison of declared and actual flows.

The study further demonstrates that the resilience of shadow infrastructure derives from its systemic architecture rather than from the durability of any individual component. The removal of specific vessels, payment instruments, intermediaries, or service providers modifies only the system's external configuration, leaving its underlying functional logic intact. This finding explains why the continuous expansion of sanctions and enforcement measures has been accompanied by the rapid adaptation and reconstruction of shadow trade networks instead of their progressive dismantling. The capacity to substitute individual infrastructural elements constitutes the principal source of resilience of contemporary shadow trade. From a policy perspective, these findings suggest that effective de-shadowing strategies should move beyond isolated interventions targeting individual vessels, transactions, cryptoassets, or

intermediaries. Greater effectiveness can be achieved by disrupting the enabling infrastructure that sustains the reproduction of shadow trade, including registration, insurance, logistical coordination, and financial servicing. Such an approach shifts the focus of international sanctions policy from combating individual manifestations of illicit activity to reducing the systemic capacity of shadow infrastructure to regenerate and sustain transnational illicit trade amid ongoing geo-economic fragmentation.

Declaration on the use of artificial intelligence. The authors declare that generative artificial intelligence tools (Grammarly Generative AI) were used exclusively for linguistic editing, stylistic refinement, and technical structuring of the text in accordance with the journal's formatting requirements. The conceptual framework, theoretical argumentation, empirical analysis, and conclusions presented in the article constitute the authors' own intellectual contribution and were not generated by artificial intelligence. The authors bear full responsibility for the scientific validity, accuracy, and integrity of the content.

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